Open Channel

VLF Radio

by Joseph J. Carr

In past editions of this column, I have written about ELF, VLF, and LF radio in conjunction with RadioScience Observing. That is, the observation of radio phenomena in the ELF, VLF, and LF portion of the radio spectrum (5 KHz to 500 KHz). This month, I want to spend a little more time on the topic.

What Are ELF, VLF, and LF?

The ELF, VLF, and LF portion of the radio spectrum are those frequencies between 5 KHz and 500 KHz. In general, about 5 to 20 KHz are considered ELF ("extremely low frequency"), 20 to 100 KHz are considered VLF ("very low frequency"), and the rest of the spectrum (100 to 500 KHz) are considered LF ("low frequency").

The Europeans have been using LF bands for AM broadcasting for years. These stations are found on 145 to 285 KHz. A notable station, often audible in the USA, is Radio 252 on 252 KHz. It runs about a 1,000,000 watts. In the middle of winter, especially, these stations are often audible in the USA and Canada. The Europeans call these frequencies "long wave."

The VLF and LF portions of the spectrum are also home to US Navy communications, WWVB (the National Institute of Standards and Technology radio station at Fort Collins, CO) on 60 KHz, and between 160 and 190 KHz a group of people called LowFers. These stations operate under Part-15 of the FCC Rules and Regulations, and are limited to 1 watt of RF power and an antenna length of 15 meters. They have demonstrated some amazing ranges given the limitations they work under.

Beginning at about 200 KHz, and continuing up to 420 KHz, are a number of Non-Directional Beacons (NDB). They are located near airports to aid navigation using airborne direction-finding equipment. NDBs tend to run about 200 watts of RF power into a simple Marconi antenna, with some coastal stations running 2.5 kW to reach further out to sea.

The frequencies in the ELF and VLF region are peculiar, especially the lower frequencies (5 to 30 KHz). These frequencies are often used for detecting solar flares and sudden ionospheric disturbances (SIDs). It seems that the level of distant stations goes up, not down, during a SID event. The same SID event that will wipe out the shortwave spectrum will enhance the ELF/VLF signal.

It does this neat trick by ionizing the ionosphere down through the D-layer. Because these frequencies have very long wavelengths, the distance between the bottom of the D-layer and the earth's surface form a waveguide. This is the reason why the ELF/VLF signal strengths increase ... waveguides are very good conveyers of electromagnetic energy!

The wavelengths of ELF, VLF, and LF stations are amazingly long. For example, at 10 KHz, the wavelength is about 18 miles long. At 76 KHz, it is about 2.46 miles, and at 137 KHz (the site of a future amateur radio allocation), it is 1.3 miles. A quarter wavelength vertical on 137 KHz would be 1,800 feet long!

The Longwave Wireless Club of America **(http://www.lwca.org)** is active in ELF, VLF, and LF Dxing and their magazine – *The Lowfer* – is obligatory for anyone doing any work in the region.

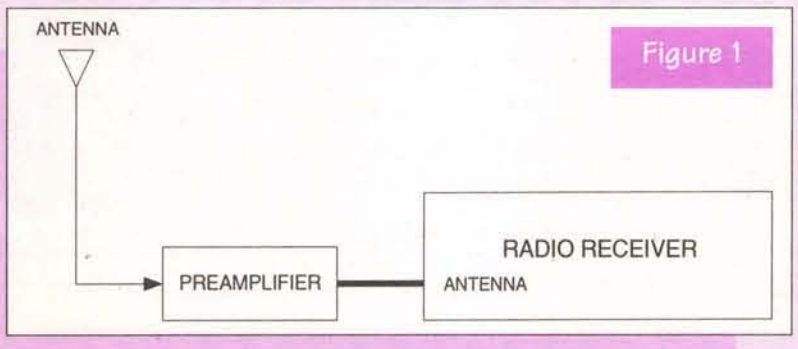


Figure 1

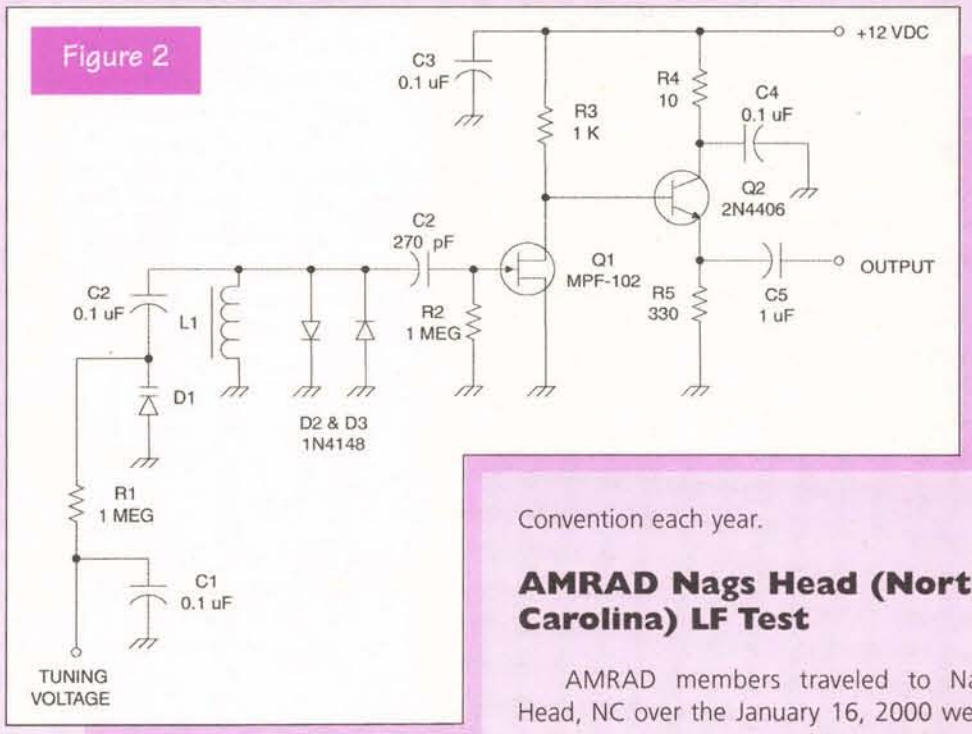


Figure 2

LF Transatlantic Challenge

The LF Transatlantic Challenge is provided by the Amateur Radio Research and Development club **(AMRAD, http://www.amrad.org)**, and is in honor of the late Peter Bobek (DJ8WL/DA0LF) in honor of his work on 160 meters and 137 KHz. The challenge is actually collectively sponsored by Deutsche Amateur Radio Club (DARC), AMRAD, and the Radio Society of Great Britain.

Two pairs of trophies will be awarded, one for each pair of amateur radio stations who make the first confirmed two-way LF transatlantic QSO on the 136 KHz amateur radio frequency allocation. The contact must be between a station on the North American continent (Canada or USA), and Europe (defined as continental Europe, Great Britain, Northern Ireland, and the Republic of Ireland). Here are the details:

1. An award will be granted to the first USA station and the first Canadian station (two awards) to receive a European 136 KHz station.

2. An award will be granted to the first European amateur station to receive either a USA or Canadian 136 KHz station.

3. The Challenge involves a pair of trophies for the first two-way Europe-USA 136 -KHz contact (once the band is allocated to amateurs by the FCC).

4. A pair of trophies will be awarded for the first Europe-Canadian 136 KHz contact.

5. Prior to the award of the trophies, certificates will be awarded to the pair of amateur radio stations who currently hold the distance record for two-way QSOs on 136 KHz.

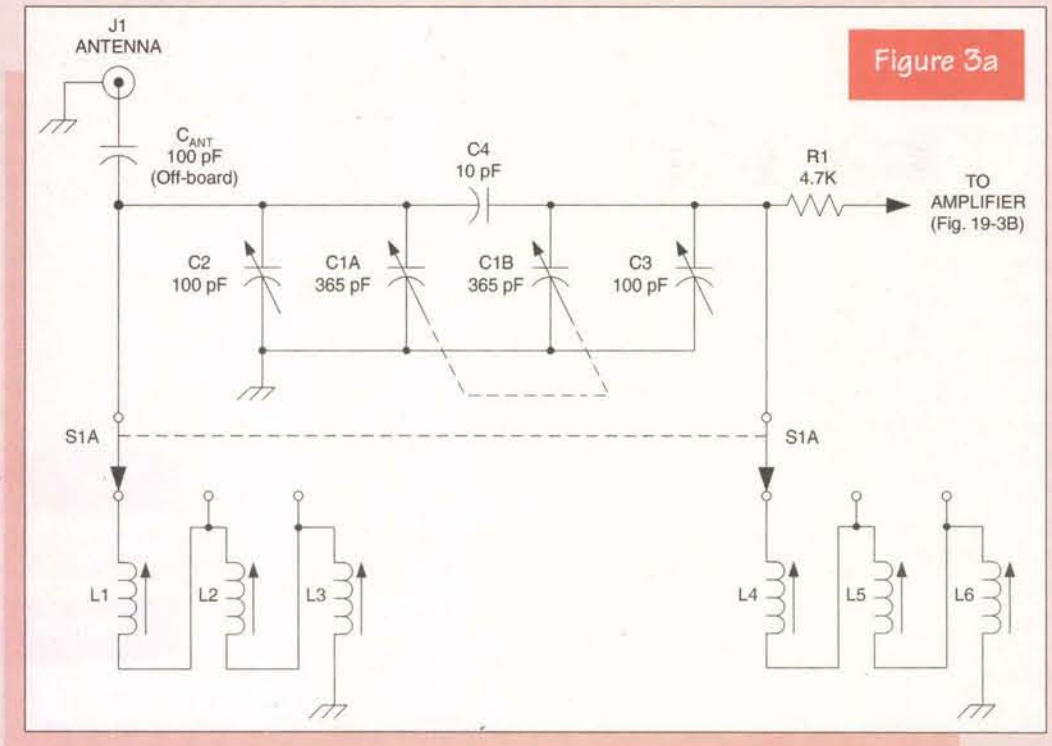
The certificates will be awarded for the distance record will be presented at the FredrichsOhafen Ham Radio event and at the RSGB International HF & IOTA Convention each year.

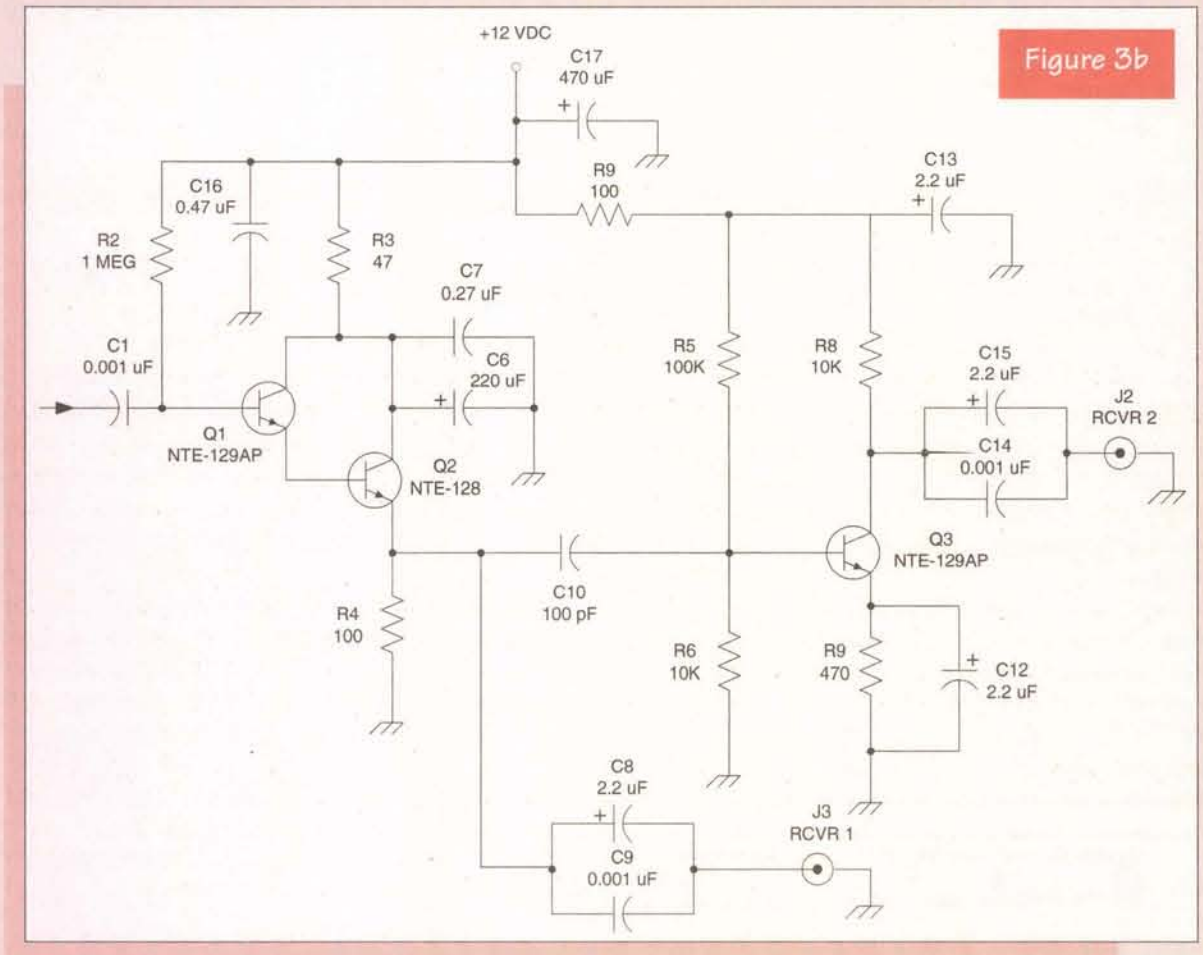
AMRAD Nags Head (North Carolina) LF Test

AMRAD members traveled to Nags Head, NC over the January 16, 2000 weekend to try some new and improved equipment on LF bands. The Nags Head site was chosen for a number of reasons. For one thing, it is almost free of the power line noise that afflicts these wavelengths at other locations in the country. Second, European signals arrive across the Atlantic Ocean. Even a short distance over land severely attenuates such signals, so they tend to be down in the mud.

ELF, VLF, and LF Preamplifiers

There are a number of shortwave receivers on the market that go down to 100 KHz, 50 KHz, or even 25 KHz in one case. The rub is that they tend to be less sensitive on these lower frequencies than they are on





the shortwave bands. In fact, they are considerably less sensitive in the VLF/LF portion of the spectrum than they are on the shortwave bands. Thus, it behooves the radioscience observer to plug in a preamplifier before the circuit to try and get that sensitivity up.

But before we tackle the subject of VLF preamplifiers, let's consider a little bit about preamplifiers in general. Figure 1 shows the placement of a preamplifier or preselector ahead of a radio receiver. The preamplifier is connected in the line between the antenna and the antenna input of the receiver. But it is not as simple as all that ... there are tigers in them thar woods!

The simple fact is that the preamplifier should not deteriorate the receiver's third-order intercept point (TOIP) and dynamic range in order to achieve its benefits. In addition, the Friis noise equation tells us that the preamplifier should have a lower noise figure than the radio receiver. This is because the noise figure of the first stage absolutely dominates the noise performance of the entire system, and the preamplifier becomes the first stage. If the criteria of no deterioration of either TOIP or dynamic range, and low noise, are met, then you are ready for a preamplifier.

Preamplifiers

Figure 2 shows the circuit for a simple cascade preamplifier consisting of an MPF-102 JFET and a 2N4406 bipolar NPN transistor. The voltage gain is about 3.3 at frequencies of 136 KHz to 250 KHz (the power gain is much larger). For this frequency range, use a 4.7 mH iron core coil for L1, and an NTE-618 varactor for D1 (the NTE-618 is available through replacement parts dealers, and has a capacitance of 440 pF at one volt, and 90 pF at eight volts DC).

Figure 3 shows a three-band VLF preselector and preamplifier for use ahead of a receiver (i.e., between the antenna and the receiver antenna terminals).

The circuit of Figure 3 has two major sections: preselector (Figure 3A) tuning and amplification (Figure 3B). The preselector tuning consists of a dual-section, reactance-coupled parallel L-C tuning network. The main tuning capacitor (C1A, C1B) is a two-section ("dual") AM broadcast variable.

Most of those capacitors are 365 pF per section (be careful, some models have an oscillator section that is less than 365 pF per section ... you want a dual 365 pF unit). Also useful are dual 380 pF, 400 pF, 440 pF, or 500 pF capacitors, all of which I've seen in recent catalogs.

The main tuning capacitor sections are trimmed by small variable capacitors (C2 and C3). For this particular project, I selected the Sprague-Goodman 10-mm type. These capacitors are designed for top adjustment, so are good for cases where the printed circuit board is mounted inside of a cabinet (the recommended approach).

The three inductors in each side of the tuning network (L1/L2/L3 and L4/L5/L6) are switch selected. The switch is a 2P3T rotary switch, i.e., it has two poles and three positions. These are a little hard to find in some stores, but the 3P3T are much easier, and will work well (just ignore the third set of contacts). The inductors are arranged so that in position "A," all three are connected in series; in position "B," two are connected in series; and in position "C," only one coil on each side (L3 and L6) is connected into the circuit. The values for these coils are:

COIL	VALUE	NUMBER
L1/L4	56 mH	TK-1721
L2/L5	56 mH	TK-1721
L3/L6	33 mH	TK-1724

The two halves of the L-C tuned circuit are coupled by a small mutual reactance. Although either capacitive or inductive reactance can be used for this purpose (although in different ways), the method used in Figure 3 is the capacitive version. Capacitor C4 is used to couple energy from one side of the L-C tank circuit to the other. A 10-pF disk ceramic or silvered mica unit will suffice. The idea is to get as small a value that will couple the two sides without allowing too much interaction. Some people prefer to use a small (<12 pF) variable capacitor in place of C4.

The tuning ranges with the coils shown were measured for the various positions of S1 as follows:

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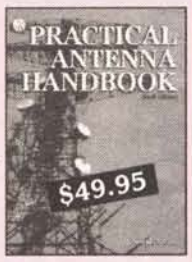

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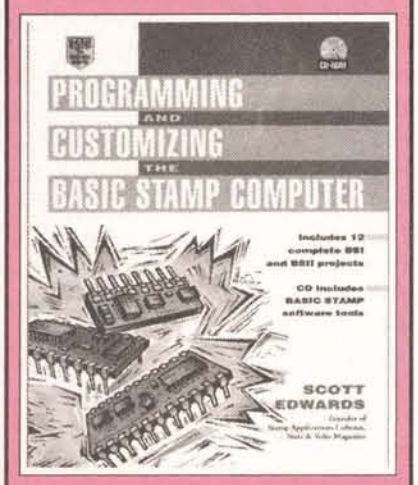
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A	20.8-36 KHz
B	25.2-44.4 KHz
C	39.1-70.8 KHz

You can alter the frequency range by selecting different coils from the same series in the Digi-Key catalog, or from some other source (including winding your own, if you are so inclined). Keep in mind that the frequencies are approximate and will differ from the frequencies found from the equation (on your calculator) because of two reasons: First, the inductances have a tolerance associated with them; and second, the inductors have significant capacitance.

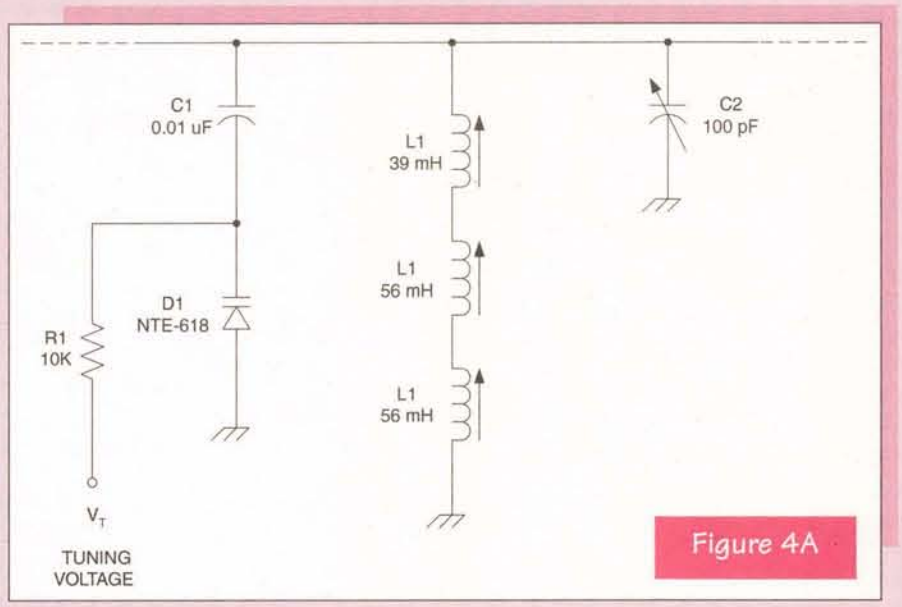

Figure 4A

The values will be within 15 percent or less, but if the frequency that you desire is close to the margin for some particular coil, then be prepared to use a different coil. If you choose to build the circuit for a different set of frequencies, then follow this rule of thumb: the frequency change is proportional to the square root of the inductance change.

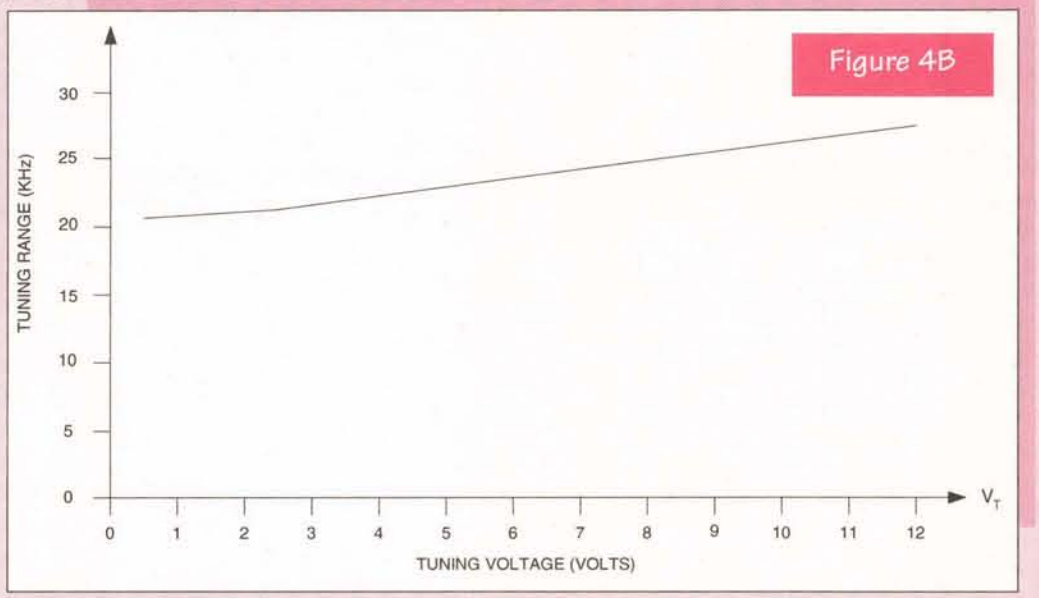

Figure 4B

The signal from the tuned circuit is coupled into a two-stage amplifier (Figure 3B) consisting of three transistors (Q1, Q2, and Q3). Transistors Q1 and Q2 are connected into the Darlington amplifier configuration, so offer a very high input impedance. This stage produces some power gain, but little voltage gain.

If it were a common emitter circuit, rather than a common collector circuit, the gain would be huge (i.e., the product of the betas of Q1 and Q2). Because Q1/Q2 is an emitter follower (common collector) amplifier, the signal is taken from the emitter of Q2 and fed to two destinations: a low gain output (OUT1) and the input of the final amplifier stage (Q1).

The circuit of Q1 is a common emitter amplifier. It uses the standard voltage divider form of biasing, with an emitter resistor to stabilize the circuit. The output of this amplifier is taken from the collector, and fed to the high gain output (OUT2).

The transistors selected for this project are the NTE-128 and NTE-129AP (also, the ECG-128 and ECG-129AP will work, as well). These parts are available from many parts distributors. Neither transistor is particularly critical, however. Q1 and Q2 were replaced with 2N4401 in one version, and worked the same as the selected transistors. Transistor Q2 can be any "audio output/video driver" NPN silicon device with a gain-bandwidth product of 100 MHz, and a beta gain around 90.

The power distribution network takes the +12 VDC power supply, and sends it to the two stages. In both stages, there is a small value resistor (R3 and R9) used to improve decoupling between stages. The actual decoupling is performed by capacitor pairs C6/C7, C11/C13, and C16/C17. In each case, a pair of capacitors – one low value and one a high value electrolytic – is used.

The high value capacitors are used to smooth power supply variations and reduce any power supply noise, as well as decoupling low frequency feedback through the DC

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For ICOM IC-W21A / 2GXAT / V21AT:(Black or Gray)

BP-132s (5w NiMH)	12.0v	1500mAh	$49.95

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power supply. The low value capacitors are used for high frequency decoupling.

Alignment of the circuit is relatively straightforward, although it requires a signal generator. The signal generator could be an RF generator that goes down to 10 KHz (a few exist), or an audio generator, or function generator that has a low impedance sinewave output (50 ohms or 600 ohms) ... which is about all of them.

Alignment begins with the tuning capacitor (C1) fully meshed, the bandswitch set to position "D," and either an AC voltmeter or oscilloscope monitoring the amplified output (OUT2). Alternatively, connect the preselector to the receiver and find the minimum frequency point on its dial.

Adjust the signal generator frequency until a peak is found. In all likelihood, the first cut will show a "double humped" tuning characteristic because the two halves of the L-C network are not adjusted to the same frequency. Adjust L3 and L6 for a peak response. Next, adjust C2 and C3 for a peak response. These adjustments are interactive, so do it two or three additional times to make sure that the actual peaks are reached.

Next, set the tuning capacitor fully open (all the way unmeshed). Find the peak frequency by adjusting the signal generator. For this adjustment, leave the inductors alone and just peak C2 and C3.

Next, align band "B" in the same manner, except that the capacitors are not trimmed. That means you adjust L2/L5 only. Finally, adjust band "A" by following the same procedure for L1/L4.

Variation on the Theme

There are two variations on the circuit that may interest some readers. First, is varactor tuning for those who can't find the dual tuning capacitors, or don't want to use the capacitor. In this circuit (Figure 4A), an AM BCB varactor (voltage variable capacitance) diode is used to replace the capacitor.

The varactor selected is the NTE-618, which has a capacitance of a few pF up to 440 pF, as the applied reverse bias tuning voltage VT is changed from 12 VDC down to 1.00 VDC. Capacitor C1 is used to provide DC blocking that keeps the tuning voltage (VT) from affecting (or being affected by) the inductors and following circuitry.

The tuning characteristic for the VLF preamplifier, found during a bench test, is shown graphed in Figure 4B. With this combination, the tuning ranged from 20.5 to 28.5 KHz when the trimmer was set to 45 pF and the inductances were set to 116.5 mH.

Reducing AM BCB Interference on VLF

The AM broadcast band covers 540 to 1,700 KHz, while the LF and VLF frequencies are those frequencies below 540 KHz. Therefore, one should not expect interference from local AM broadcast stations while noodling around in the "down unda" bands, right? No, not by a long shot. There are two basic reasons.

First, the AM stations may tend to be very local. Second, radio stations tend to be high powered. One location where I lived was known locally as "Intermod Hill" because there were a large number of radio transmitters up there, including two FM BCB (50 kw each) stations and one 5,000 watt AM BCB station. Living just a few blocks from that 5,000-watt gigablaster tore a hole in every receiver I owned. With such strong field strengths, almost all receivers overloaded.

Incidentally, the way I graded receivers in those days was how free they were from such interference. And it wasn't always the most expensive model that was the most free of problems.

A way to solve the problem is to use a low-pass filter (LPF) ahead of the receiver that has a cut-off frequency somewhere below 540 KHz. Figure 5 shows a seven-element LPF with a 0.1 dB ripple factor, designed for 50-ohm input and output impedances. The LPF consists of four inductances (L1-L4) and three capacitors (C1-C3). Each capacitor is made up of two parallel capacitances in order to obtain the correct capacitance.

Those capacitors should be a relatively stable, five percent tolerance, type such as the Panasonic B-Series polyester or V-Series metallized film capacitors. For receive-only applications, the voltage rating is not an issue, so 50-WVDC capacitors in those series will work nicely.

The inductance values shown in Figure 5 are for the VLF version of the tuner, for which a 120 KHz -3 dB cut-off frequency is specified. The 75-mH inductors are Toko TK-4256, while the 130-mH inductors are Toko TK-4262. If you want to make the LPF work for a different cut-off frequency, then consult Table 1 for component values:

The layout of the LPF circuit should follow "good low frequency RF practices," which means that you want at least a small separation between the inductors. Construction on perforated board is quite satisfactory. My initial version was built "rat's nest" style on printed circuit perf-board. That form has printed circuit connection points on a 0.1 X 0.1 inch pattern, so is easy to solder to and use.

By the way, the same circuit can be used for any frequency. This LPF is somewhat universal. To find the values of the components, use the following formulas: L1 = L4 = 9.4/FMHz; L2 = L3 = 16.68/FMHz; C1 = C3 = 4538.9/FMHz; and C2 = 5008.3/FMHz, where FMHz is the frequency in MegaHertz. The coils can be made from T-37-xx toroidal cores, or selected from the Toko coils. Select fixed coils with a 5 mm (0.2 inch) pin spacing ... which is nearly all of them in that catalog. **NV**

TABLE 1

BAND	L1/L4	L2/L3	C1	C2	C3
<300 KHz	33 mH	56 mH	0.015 mF	0.0167 mF	0.015 mF
<500 KHz	18 mH	33 mH	0.009 mF	0.01 mF	0.009 mF

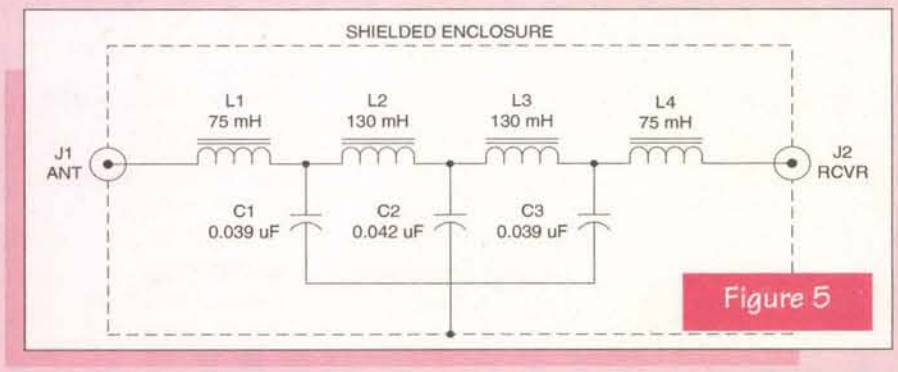

Figure 5

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